External Peer Review of a Proposed Amendment to the Water Quality Control Plan for California Ocean Waters to Address Desalination Facility Intakes, Brine Discharges, and to Incorporate other Nonsubstantive Changes

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Introduction and Scope

This report presents a scientific peer review of a Proposed Amendment to the Water Quality Control Plan for California Ocean Waters to Address Desalination Facility Intakes, Brine Discharges, and to Incorporate other Nonsubstantive Changes (hereafter, the Amendment). My expertise is in Environmental Fluid Mechanics, and this review covers topics of turbulence, entrainment, general hydraulics, outfall design, and mixing zone modeling. As such, the substantive comments of this review focus on the dilution and turbulence aspects of Science Conclusion 4 that “Multiport diffusers and commingling brine with other effluents can dilute brine discharge and provide protection to aquatic life.”

As requested, I have reviewed the complete text of the proposed Amendment, the Draft Staff Report on the Proposed Amendment (the Staff Report in the following), the report of the External Review Panel III (ERP III, Foster et al. 2013), and several of the cited references. As an expert on jets, plumes, and outfall diffusers, I also bring to the review a strong background in the literature on jets and plumes, multiport diffuser design, and the methods commonly used in their analysis.

This review is structured in three parts. In the first part, I address the overall fluid mechanics statements in the proposed Amendment and the specific content of Science Conclusion 4. My overall conclusion expressed in this section is agreement with the fluid mechanics contained in the Amendment and the Staff Report. In the remaining two sections, I address specific aspects of the amendment that would benefit from improved clarity or slight revision. In the second part, General Comments, I discuss common themes or elements that span multiple sections of the proposed Amendment as well as topics that may not have been addressed directly in the Amendment text. The second section, Specific Comments, presents a few detailed observations that pertain to a single phrase, sentence, or paragraph. These are mostly areas where I felt the text was ambiguous or misleading; my comments seek to focus the intent of the Amendment through each of these recommendations.

Science Conclusion 4

As an overall conclusion, I am in agreement with the scientific statements regarding fluid mechanics processes in the proposed Amendment and in the Staff Report regarding Science Conclusion 4. As a fluid mechanics expert, I have limited my review to flow, mixing, and turbulence. Hence, this review does not evaluate the water quality control standard itself or the biology or toxicology behind it. In particular, I agree with the following findings:

- Brine discharge from desalinization plants will normally be negatively buoyant when discharged to the coastal ocean, requiring an outfall design to promote rapid mixing of the brine discharge to achieve the water quality control standard of 2 ppt salinity above background concentration at the end of the regulatory mixing zone.

- Commingling brine discharge with opportunistic effluent from other sources (e.g., cooling water or effluent from wastewater treatment plants) can dilute brine and reduce its negative buoyancy before release. In the case of wastewater discharge, which is typically close to the density of freshwater, commingled effluent could be positively buoyant at the point of discharge. Positively buoyant discharges would not descend to the sea floor or impact the benthos.

- Multiport diffusers are a common and reliable means to discharge effluent to the coastal ocean. These facilities have a strong history of use, including for brine discharge. Proper design can easily achieve a 20-fold dilution within the stated regulatory mixing zone requirement of 100 m laterally from the point of discharge.

- High turbulence has been cited as a mechanism for organism mortality in multiport diffusers. The analysis presented in Foster et al. (2013) is an accurate means to evaluate the eddy sizes and available energy in a jet from a multiport diffuser. Their conclusion that 23% or less of the total entrained volume required to meet the dilution requirements would be subject to high levels of turbulence is a conservative upper bound.

- Flow augmentation also has the potential to achieve the 20-fold dilution required to meet the stated water quality control criteria. Since flow augmentation will not be allowed to be discharged through a diffuser, the intake will have to be 20 times greater than the desired potable water stream in order to achieve the required dilution within the mixing zone.

These conclusions are the main substance of the proposed amendment as it pertains to my expertise, and I agree that they are based on sound science.

General Comments

This section outlines a few topics that span multiple parts of the Amendment or that were not specifically addressed in the amendment text. Following a short discussion of each topic I suggest a few specific parts of the amendment that could be revised to address the general comment.

Negatively buoyant plumes and anoxia

Paragraph L.2.c.(4) states that an operator or owner must "design the outfall so that discharges do not result in dense negatively-buoyant plumes that result in adverse effects due to elevated salinity or anoxic conditions occurring outside the brine mixing zone." Strictly speaking, this goal cannot be achieved for a typical discharge that does not have commingling of fresh wastewater. For a typical brine discharge, the discharge salinity will be about twice ambient salinity, and an infinite dilution would be required to completely remove its elevated salinity. Moreover, the discharge will be negatively buoyant at the diffuser and may exit the mixing zone as a negatively-buoyant plume on the sea floor. These facts are acknowledged by the ERP III as they write describing Figure 1 on page 1 of their report.

I believe the intent of this paragraph is to require that:

- The region outside the regulatory mixing zone must not have an anoxic region associated with the discharge

- The salinity must be reduced to a maximum of 2 ppt above background before exiting the regulatory mixing zone.

This opening sentence could, thus, be revised to state: "design the outfall so that the diluted plume exiting the mixing zone meets the water quality standard set for salinity and so that anoxic conditions resulting from the discharge do not exist at the sea floor or in the water column outside the mixing zone." This acknowledges that the discharge may be a negatively-buoyant plume exiting the mixing zone and defines what is meant by "elevated salinity". It further requires that the region affected by the discharge beyond the mixing zone remain above the anoxic limit.

This comment also pertains to the text on p. 73 of the Staff Report where "dense outfalls that cause anoxia" are not permitted. Revise this section to state that anoxic conditions are not permitted in the region influenced by a brine discharge outside of the mixing zone. Allow, however, for the plume to be negatively buoyant from the discharge to the far-field as would be the case for any discharge of elevated salinity (see, again, Figure 1 of the ERP III report).

Several other parts of the Staff Report also refer to "near ambient" salinity, and on page 82, they characterize the discharged plume as non-buoyant outside the regulatory mixing zone. I point out that, without adding water with salinity below that of the intake, a brine discharge will remain with elevated salinity and negative buoyancy until achieving infinite dilution. Water can be added with salinity below that of the intake either through commingling or by discharging the brine in a coastal region with vertical salinity stratification such that upper layers of the water column have salinity below the intake value (see comments in the next section). However, neither of these conditions are required of all plumes; hence, the report should assume the plume may remain negatively buoyant and with elevated salinity (above background, but less than 2 ppt above background) outside the regulatory mixing zone for a long distance into the far field of the plume.

Please see Figure 1 in the ERP III report for an experimental result showing the dense bottom plume exiting the near field. Throughout the ERP III report it is clear that the authors acknowledge that the final stage of the discharge will be a dense plume traveling along the bottom. The goal of the design should be that the dilution is adequate to prevent this plume from becoming a barrier between the benthos and the upper water column. This is achieved by requiring the plume to remain oxygenated throughout its trajectory.

Recommended revisions to the Amendment:

- L.2.c.(4). Per the recommended revision stated above, recognize that the plume leaving the mixing zone may be negatively buoyant and of elevated salinity, and specify that anoxic conditions are not allowed in regions affected by the discharge outside the mixing zone.
- Search the amendment text for "non-buoyant plume" and decide whether there may be an elevated salinity that is nonetheless within the water quality standard. Plumes with elevated salinity would generally be expected to be negatively buoyant.
- As I read the Amendment, anoxia would be permitted within the mixing zone. If this is the case, no revision is necessary. If not, please clarify in L.2.c.(4) that anoxia is not permitted in any part of the discharge plume.

Recommended revisions to the Staff Report:

- Revise page 73 as noted above to clarify that a dense plume with elevated salinity is permitted, but that anoxia within the plume is not. Specify whether anoxia is permitted inside the mixing zone.
- Search the document for "near ambient salinity" and "non-buoyant plume." Ensure that the text does not imply the discharge plume with have infinite dilution.

Density Stratification

On a similar topic, the Amendment does not make any mention of vertical variation of ambient salinity or temperature in the water column, either at the intake or the discharge. Vertical variation is commonly termed stratification and results in a stable density profile with heavier water at the bottom and lighter water at the surface.

Stratification can be important for an outfall design for two reasons. First, as the discharge jet entrains ambient water on its ascent, it becomes increasingly less negatively buoyant. In a density stratified ambient, it is possible that the jet could become neutrally buoyant in the water column, forming an intrusion layer suspended between the sea floor and the free surface. In fact, most wastewater treatment plant discharges are designed to do this so that diluted sewage is sequestered below the sea surface. For a brine discharge, this has the advantage of keeping the diluted brine off the sea floor. Second, in the case of significant salinity stratification due to freshwater inputs along the coast, it is possible that a brine jet could mix to a salinity at or below the intake salinity by entrainment of ambient water into the jet. This has the advantage of eliminating the elevated salinity of the discharge.

I acknowledge that density stratification and salinity stratification are quite variable along the coast, and that a brine discharge can be easily designed to meet the Water Quality Control Standards at the end of the mixing zone without taking advantage of the ambient stratification. I would recommend, then, that the amendment acknowledge that impact could be reduced when favorable ambient stratification exists and allow operators to include stratification in their mixing zone modeling when historic data are available to select a typical vertical profile of salinity and temperature.

Recommended revisions to the Amendment:

- L.2.d.(2)(b). Suggest here that ambient stratification could be used to trap and dilute the plume. Revise text to state "…shall be engineered to maximize dilution, minimize the size of the brine mixing zone, minimize the suspension or benthic sediments, <u>*minimize the contact of the plume with the bottom*</u>, and minimize marine life mortality."

- L.2.e.(1)(b). The modeling study should be allowed to account for vertical variation of salinity and temperature based on analysis of historical data. Add the sentence: "Average vertical variation of salinity and temperature may be assessed from historical profiles when available and included in the mixing zone modeling."

Recommended revisions to the Staff Report

- Section 8.6.2.2. Add a paragraph summarizing the potential positive benefits of ambient stratification of temperature and salinity. Provide some guidance on whether vertical stratification may be used in mixing zone modeling and how the assumed profiles of temperature and salinity may be obtained (e.g., as time average like natural background salinity or some other approach).

Background Concentration

Paragraph L.3.b.(2) presents the equation to calculate the allowable salinity of the effluent so that the discharge will meet the water quality control standard of 2 ppt above the natural background at the end of the regulatory mixing zone. The Definition of Terms section of the amendment defines the natural background concentration as a 20-year historical average or an average based on 3 years of intensive monitoring when historical data are not available. As I understand the amendment, this sets the natural background concentration as a constant and does not allow for seasonal variability in the background salinity. Figures 8.5 and 8.6 in the Staff Report show that background salinity at a given site can vary over 2 ppt over seasonal and annual time scales. By setting the natural background concentration to a constant it would be possible that seawater entering the intake of a desalinization plant would already exceed 2 ppt above a constant average background value. Hence, a means to include natural variability is needed.

The definition of the natural background concentration in the Amendment hints that a nearby reference station could be used to provide a variable background concentration against which the 2 ppt above background standard could be applied. There is not much guidance there, and it seems to me that the amendment itself should acknowledge the need for a variable background reference and propose a means to establish its value. Since the intake is required to be designed in a way that it does not take in water from the discharge, the intake salinity would be a reasonable reference value for the background.

Recommended revisions to the Amendment:

- L.3.b.(2)(c). If the intent of the alternative maximum value is to allow for values greater than 2000 mg/l, revise to clarify this. If not, the text is acceptable as it is.

- L.2.b.(2). Add a new section (d) to state how a time-varying value of the natural background concentration could be obtained for the purposes of enforcement.

- NATURAL BACKGROUND SALINITY. Explain in the amendment what the function is of the reference location with similar background salinity that is to be used for comparison in ongoing monitoring of brine discharge. Does this mean that the background value is not a constant in the equation in L.3.b.(2) during enforcement? The Amendement is somewhat vague to my reading as to whether the background value that sets the 2 ppt above background standard is a constant or is allowed to be variable in time during operations.

Recommended revisions to the Staff Report

- Section 8.7.2. Specify whether a time-varying value of the natural background salinity may be used for the purpose of enforcing the 2 ppt above background standard and how that background salinity is to be established.

Mortality estimates

The ERP III report provides good detail on the estimation of mortality of organisms entrained into multiport diffusers as a result of turbulence in the jet. I am in agreement with the methodology applied by Roberts and Vetter (Appendix 1 of Foster et al. 2013). The Kolmogorov length scale is the correct scale for the fine-scale eddies in a jet. Their estimates of the Kolmogorov length scale use the correct scaling relationships and empirical coefficients. The estimate that 23% of the total entrained volume required to meet the 5% dilution standard could be in a high-turbulence region of the plume is a conservative upper-range estimate. It is likely that less of the total volume would contain lethal levels of turbulence for passive organisms.

Recommended revisions to the Amendment:

- I am in agreement with the amendment.

Recommended revisions to the Staff Report

- I am in agreement with the Staff Report.

Mixing Zone Definition

Page 97 of the Staff Report describes the typical definition of a mixing zone used in the California State water quality standards. The general definition of a mixing zone is the region near a discharge where dilution is allowed to occur and upstream of where a water quality standard is going to be enforced. A regulatory mixing zone is an operational definition of the extent of this dilution region. In other parts of the water quality code in California, the mixing zone is apparently defined by the dilution and does not have a fixed lateral extent. The proposed amendment for brine discharges uses a different definition, equal to 100 m laterally from the discharge. This definition is a common one, but it is different from other parts of the water quality control code, and it may be advisable to have a consistent definition within the State.

Recommended revisions to the Amendment:

- BRINE MIXING ZONE. Consider whether this definition is consistent with mixing zone definitions in other parts of the California water quality code. If not, consider whether to revise to match other definitions.

  It also seems that the definition confuses the definition of mixing zone with regulatory mixing zone. This definition states that the mixing zone is the region with salinity more than 2 ppt above background and that the regulatory mixing zone extends to a maximum of 100 m laterally from the discharge point, yet the definition excludes the important distinction "regulatory." Consider having two definitions, one for mixing zone and one for regulatory mixing zone.

Recommended revisions to the Staff Report

- If the Amendment is modified to match mixing zone definitions elsewhere in the California water code, update the Staff Report to be consistent with the Amendment.

  Search "mixing zone." If the reference is to the region with salinity greater than 2 ppt above background, leave the text as is. If the reference is to a region extending up to 100 m laterally from the discharge, revise the text to read "regulatory mixing zone."

Area or Volume of Impact Computed for Mitigation

Page 81 of the Staff Report states in the case of a multiport diffuser discharge that the impacted region can be estimated as the area or volume for which the salinity exceeds 2 ppt within the mixing zone. This is ambiguous for two reasons. First, a multiport diffuser jet is a three-dimensional object, so that its areal extent is hard to quantify. Certainly the radius to the point where the salinity is 2 ppt above background can be estimated, and the region inside this radius could be the impacted area. However, this point can occur high in the water column, making a lateral distance ambiguous. Second, the discharge jet is a narrow, boundary layer flow so that the volume contained inside the jet may be quite small. Estimating this volume is straightforward using jet mixing models. The difficulty comes in converting this impacted volume to the necessary mitigation area. All of the mitigation requirements are on an acerage-basis. No guidance is provided to convert an impacted volume inside the mixing zone to a required mitigation area.

The Amendment in section L.2.e.(1)(b) states that the area approach is required for estimation of the impacted region. This could be made more precise by requiring that the projected, plan-view area in which salinity exceeds 2 ppt above natural background be used.

Recommended revisions to the Amendment:

- L.2.e.(1)(b). Revise text to refer to the "projected, plan-view area."

Recommended revisions to the Staff Report

- Page 81. Remove text referencing a volume estimate for the impacted region; specify that the lateral distance from the discharge used to estimate impacted area should be a projected, plan-view distance.

Detailed Comments

Proposed Water Quality Control Amendment

- L.2.b.(4). "bathymetry…seafloor topography." These are the same thing but are listed as different measurements which must be made in a comprehensive list. Later, in paragraph L.2.d.(1)(a)i., the term "benthic topography" is used. Recommend using one term for the bottom topography and using that term throughout.

- L.2.d.(1)(a). "require subsurface intakes unless … are infeasible." Recommend to add a statement here why subsurface intakes are required so that there is a relevant benchmark against which to determine if surface intakes are infeasible. For example, L.2.d.(2)(a) states "the preferred technology to minimize intake and mortality of marine life…" [underline added]; hence, the justification is stated with the requirement. L.2.d.(1)(a) could be revised similarly: "to eliminate intake and mortality of marine life, subsurface intakes that use natural filtering of the sediments are required unless…"

- L.2.d.(1)(c)iii. Screens are designed to stop marine life entrainment, but I assume the eggs and larvae and some juvenile fish caught by the screens become impinged, unable to get off of the screens. What are operators required to do with the debris and organisms stopped by the screens? May they dispose of it? In that case, all organisms impinged on the screens will suffer mortality and the screen size need only be large enough to prevent entrainment of mobile organisms capable of not becoming impinged. If impinged organisms cannot be disposed of, should the screens be backwashed? I did not notice any guidance in the Amendment.

- L.2.d.(2)(a). Commingling is preferred with wastewater that "would otherwise be discharged to the ocean." This statement can end here. Adding, "unless the wastewater is of suitable quality and quantity to support domestic or irrigation uses," is unnecessary. Presumably, if the available wastewater for commingling is of suitable quality, it would not be otherwise discharged to the ocean. It seems logical that commingling should be allowed with any waste stream that "will otherwise be discharged to the ocean." Some other part of the Control Plan should clarify that wastewater of suitable quality and quantity to support domestic or irrigation uses should never be discharged to the ocean.

  Also, the next paragraph introduces multiport diffusers, which is a discharge technology. The present paragraph is an effluent technology, but there is no mention of the type of discharge. I would assume that a commingled flow would also be discharged via multiport diffusers. It seems this paragraph and the next should go together and not be unique from one another.

- L.2.d.(2)(b). "Multiport diffusers are the next best…" Revise to "Multiport diffusers are the next preferred…" Also, see the comment above for L.2.d.(2)(a). It seems that multiport diffusers are not an alternative to commingling a waste stream; rather, these technologies would likely be used together.

- L.2.d.(2)(c). This sentence is grammatically incorrect. Operators are required to analyze for what? There needs to be an objective function to the analysis. Revise to state "…analyze the brine disposal technology or combination of brine disposal technologies to determine which option best reduces the effects…"

- L.2.d.(2)(d). The owner must evaluate all sources of marine mortality, including inside the desalinization plant. However, throughout the amendment it is assumed that processes in the plant will kill all organisms entrained through the intake. It seems to me that the operator should be required to assess mortality associated with the intake and the discharge only: any organism entrained through the intake is assumed lost. Rather than requiring the owner to estimate marine life mortality that occurs inside the plant, provide that as an option in the case there is evidence that the mortality is less than 100% and the owner would like to establish that fact.

- L.2.d.(2)(d)iii. The operator must estimate mortality inside the desalinization plant (e.g., water conveyance, in-plant turbulence or mixing); yet, the amendment already assumes 100% mortality for organisms that pass through the intake. Hence, this paragraph should be revised to "Estimate marine life mortality that occurs as a result of the waste discharge and assume marine life mortality for organisms passing through the intake to be 100% as a result of water conveyance, in-plant turbulence, and osmotic variability unless there is evidence to the contrary."

- L.2.d.(2)(e)i. Operators who choose flow augmentation must use low turbulence intakes (e.g., screw centrifugal pumps or axial flow pumps) and conveyance pipes. However, the ERP III report states that there is no evidence that such pumps 1.) are sub-lethal or 2.) can deliver the required flow volumes. Moreover, in the following paragraph iii, organisms entrained by flow augmentation are assumed to have 100% mortality unless demonstrated otherwise through studies within three years of operation. Hence, at the design and initial permitting stage, 100% mortality inside the plant must be assumed. Owners should have the option to assume 100% mortality and to use the most efficient pumps available.

- L.2.d.(2)(e)vi. Why is flow from flow augmentation prohibited from being discharged through a multiport diffuser? Because of high turbulence? Or some other reason? As stated, this seems arbitrary, and the rationale should be given.

- L.3.b.(2)(c). 2000 mg/l above background is set as the maximum allowable salinity increase allowed at the end of the regulatory mixing zone. Can the alternative value substituted by a facility-specific study be higher than 2000 mg/l? As written, I would say legally it could not be. However, it seems the intent of this section is to permit higher levels. Revise for clarity.

- BRINE MIXING ZONE. The definition here is not clear. Various definitions used here include salinity above 2 ppt above background, a lateral distance of 100 m, or a region determined by modeling. For clarity, simply state that the regulatory mixing zone extends to 100 m laterally from the discharge.

- MULTIPORT DIFFUSERS. These can be used for more than just brine. Revise to remove brine from the definition.

- NATURAL BACKGROUND SALINITY. Is the reference location suggested by this definition an acceptable value of background concentration for the equation in section L.3.b.(2)?

Staff Report

- Citation format is unusual. It appears that citations are placed outside the end of the sentence being cited. As in: "concentration found in empirical studies. (citation) New sentence." I have never seen this format before and find it ambiguous. Does the citation apply to the first sentence in the above example or the new sentence? Citations belong within the sentence being cited: "concentration found in empirical studies (citation)."

- P. 65. Bulleted list. Revise "statistical certainty" to "statistical uncertainty." Statistics are typically used to quantify uncertainty. Unless you sample a whole population, statistics cannot quantify certainty.

- P. 92. Discussion of mortality. If 100% of organisms that pass through an intake die, then there is no remaining mortality to quantify inside the plant.